



## A discussion of the IEEE standard on transition and pulse waveforms, Std-181-2003

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### Abstract

The IEEE Std-181-2003, which is a new standard on pulse techniques and definitions, has been recently published. This standard was written to replace the withdrawn IEEE standards, Std-181-1977 and Std-194-1977. The Std-181-2003 combines information from both of the withdrawn standards. The new standard has incorporated new definitions not contained in the withdrawn standards and deleted and clarified definitions contained in the withdrawn standards. The new standard also provides examples of different waveform types and incorporates algorithms for computing waveform parameters, both of which were not contained in the withdrawn standard. This paper introduces the Std-181-2003 by describing its contents and changes relative to the withdrawn standards.

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### 1. Introduction

The purpose of the Std-181-2003 is to facilitate accurate and precise communication concerning parameters of transition, pulse, and related waveforms and the techniques and procedures for measuring them. The terms defined in this standard are applicable to many industries, such as, biomedical, electronic, energy, and aerospace. The widest use, however, may be in the electronics industry because of the broad applicability of

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electrical pulse technology, such as in the computer, telecommunication, and test instrumentation industries. The development of unambiguous definitions for pulse terms and the presentation of methods and/or algorithms for their calculation is important for communication between manufacturers and consumers within the electronics industry. The availability of standard terms, definitions, and methods for their computation helps improve the quality of products and helps the consumer better compare the performance of different products. Improvements to digital waveform recorders have facilitated the capture, sharing, and processing of waveforms. Frequently these waveform recorders have the ability to process the waveform internally and provide pulse parameters. This process is done automatically and without operator intervention. Consequently, a standard is needed to ensure that the definitions and methods of computation for pulse parameters are consistent.

The Subcommittee on Pulse Techniques (SCOPT) [1] of the IEEE Technical Committee 10 (TC-10, Waveform Measurement and Analysis) is responsible for maintaining the IEEE Std-181. The Std 181-2003 replaces the withdrawn IEEE standards, Std-181-1977, Standard on Pulse Measurement and Analysis by Object Techniques [2], and IEEE-Std-194-1977, Standard Pulse Terms and Definitions [3]. These withdrawn IEEE standards were adopted in 1987 by the International Electrotechnical Commission and are the IEC 60469-2, Pulse Techniques and Apparatus, Part 2: Pulse measurement and analysis, general considerations [4], and IEC 60469-1, Pulse Techniques and Apparatus, Part 1: Pulse terms and definitions [5].

The purpose of this paper is to introduce the new IEEE standard by extracting the key and most technologically important terms and presenting their definitions and associated algorithms, if available. The most basic terms are given in Section 2. Section 3 provides definitions of some waveform parameters and section 4 contains some algorithms for finding the most frequently measured waveform parameters. Further discussion of this standard can be found in [6]. In Sections 2–4, the term to be discussed is given

in bold-face type and followed immediately by the definition of the term as taken from the Standard (within quotations). After the definition, a brief description of the term is given. References to clauses herein are references to clauses in the Standard.

## 2. Basic waveform terms

The basic terms typically do not have an associated algorithm as they are more descriptive.

**Signal**—“A signal is a physical phenomenon that is a function of time.” This describes what is being measured and, as will be seen, is distinguished from a waveform.

**Waveform**—“A waveform is a representation of a signal (for example, a graph, plot, oscilloscope presentation, discrete time series, equations, or table of values). Note that the term waveform refers to a measured or otherwise defined estimate of the physical phenomenon or signal.” Waveforms (see Fig. 1) are the things that are actually observed, acquired, and analyzed.

**Pulse waveform**—“A waveform whose level departs from one state, attains another state, and ultimately returns to the original state (see Fig. 2). As defined here, a pulse waveform consists of two transitions and two states. Alternatively, a pulse waveform can be described as a compound waveform consisting of the sum of a positive (negative) step-like waveform and a *delayed negative* (positive) step-like waveform both having the same unsigned waveform amplitude.” A pulse waveform is a compound waveform because it consists of two states and two transitions, a negative-going and a positive-going transition. In addition to being defined as a compound waveform, the Standard provides the above definition for a pulse waveform because it is one of the most commonly used compound waveforms.

**Transient**—“A transient is any contiguous region of a waveform that begins at one state, leaves and subsequently returns to that state, and contains no state occurrences.” Transients are the anomalous events often observed in a waveform. They include glitches, spikes, and runs. These terms are also defined in the Standard.

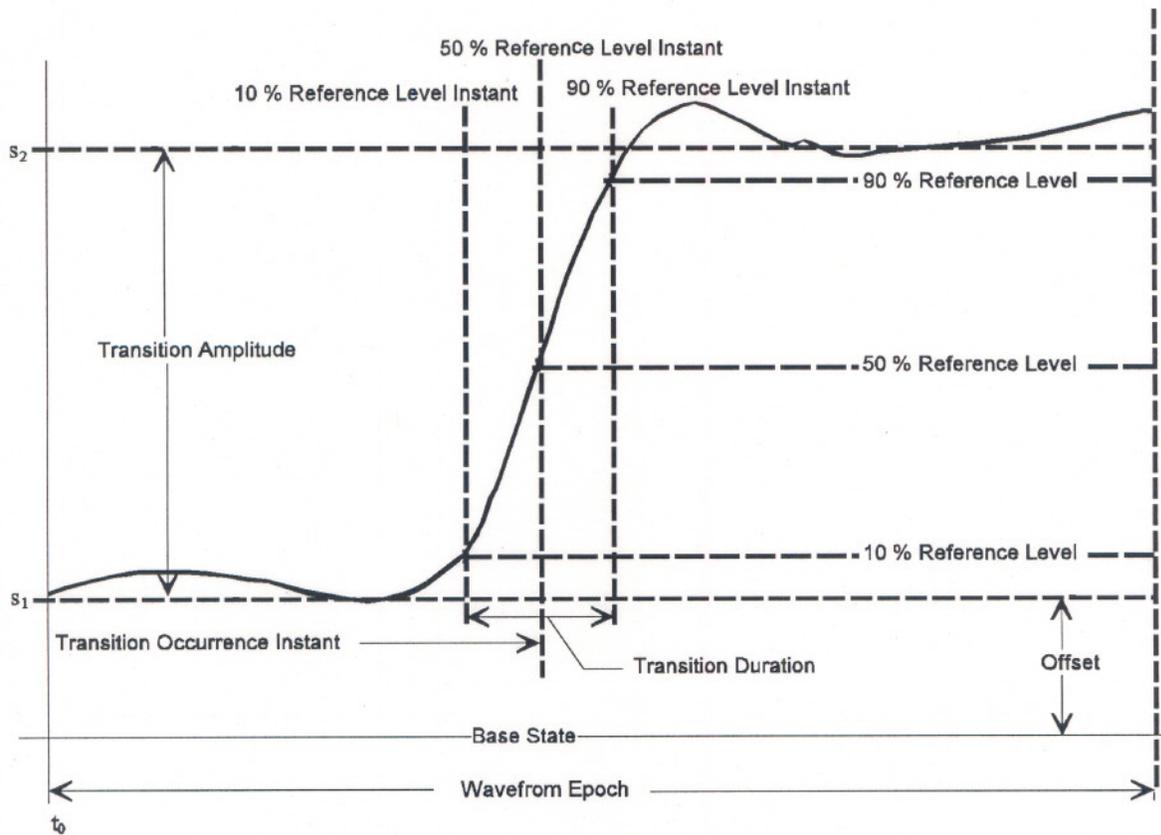


Fig. 1. Positive-going transition.

*Transition*—“Contiguous region of a waveform that connects, either directly or via intervening transients, two state occurrences that are consecutive in time but are occurrences of different states.” Transitions, in conjunction with states, comprise a waveform.

### 3. Basic waveform parameters

The basic waveform parameters are fundamental to the description, discussion, and computation of all other waveform parameters. The basic waveform parameters do not require the definition or computation of other parameters, except for reference level instant. The Standard requires that the user specify the computation method used if more than one method is allowed, such as for states. Similarly, if more than one option is allowed for

a given computational method, the user must specify the option used, such as using the 20% and 80% reference levels to compute transition duration instead of using the 10% and 90% reference levels. Reference level will be discussed in this section and transition duration in the next section.

*State*—“A particular level or, when applicable, a level with an associated upper and lower state boundary. Unless otherwise specified, multiple states are ordered from the most negative level to the most positive level, and the state levels are not allowed to overlap. The most negative state is called state 1. The most positive state is called state  $n$ . The states are denoted by  $s_1, s_2, \dots, s_n$ ; the state levels are denoted by  $\text{level}(s_1), \text{level}(s_2), \dots, \text{level}(s_n)$ ; the upper state boundaries are denoted by  $\text{upper}(s_1), \text{upper}(s_2), \dots, \text{upper}(s_n)$ ; and the lower state boundaries are denoted by  $\text{lower}(s_1), \text{lower}(s_2), \dots, \text{lower}(s_n)$ . States, levels,

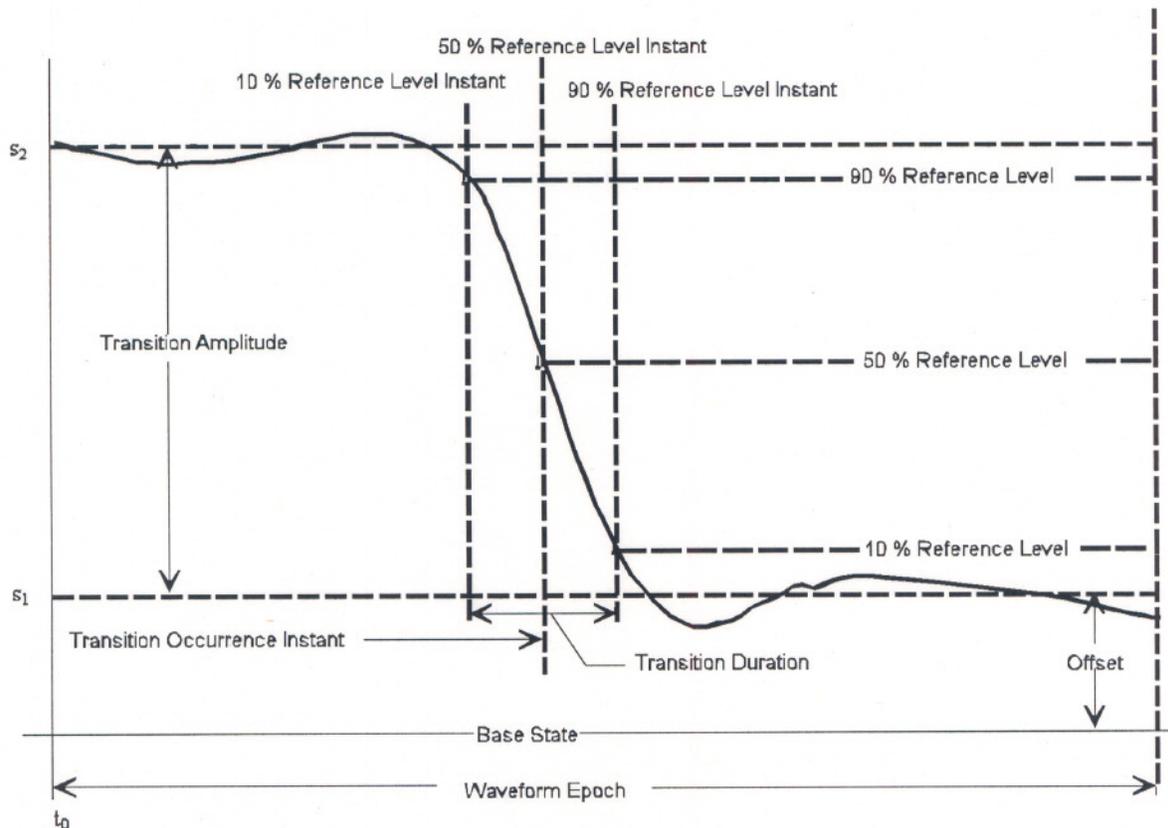


Fig. 2. Negative-going transition.

and state boundaries are defined to accommodate pulse metrology and digital applications. In pulse metrology, the levels of a waveform are measured and states (with or without associated state boundaries) are then associated with those levels. In digital applications, states are defined (with state boundaries) and the waveform values are determined to either lie within a state or not. This term is important because all level (voltage, current, etc.) related parameters, such as amplitude, overshoot and undershoot, etc., are based on the states of a waveform. A state is a nominally constant-valued region of the waveform. In the withdrawn standards, the word “line” was used to describe the value corresponding to these nominally constant-valued regions of a waveform. Terms such as “topline” and “baseline” (or “bottom line”) were used. However, “line” is a graphical description and not an appropriate term for electronic

computation of waveform parameters or for describing the output of a physical device. The term presented in the Standard is “state.” State is also consistent with the description of constant-valued currents or voltages from the output of actual electronic devices. States are numbered starting at the most negative and ending at the most positive, and are designated by  $s_1, s_2, \dots, s_n$ , where  $s_n$  is the most positive state and  $s_1$  is the most negative state for an  $n$ -state waveform. For example, the waveform shown in Fig. 1 is a two-state waveform. Each state has an associated level which describes the value (number with units) for that state. For example, the two-state waveform in Fig. 1 can have  $s_1 = 0\text{ V}$  and  $s_2 = 0.25\text{ V}$ . Associated with a state are upper and lower boundaries, and a waveform is said to be in this state if its values are within these boundaries for a user specified duration. The difference between the upper bound-

ary and lower boundaries can be different for each state.

The standard provides and/or identifies several methods for determining the levels associated with a state. These methods include those based on histogram methods (three are described), the extreme waveform values, the final and initial waveform values, user-defined values (which should be based on the user's knowledge of the device under test), static levels (if the pulse source can also output dc values to the same connector from which comes the output pulse), and auxiliary waveforms (in the case where there is insufficient data in one waveform to compute all the desired waveform parameters). The histogram techniques may use different bin sizes and the user may select if the histogram modes, means, or medians will be used. The effect of different histogram implementations have been described elsewhere [7]. This study [7] does show that only for pathological cases will there be a noticeable difference between results from the different methods.

*High and low state*—“Unless otherwise specified, the high state of a waveform is the most positive state within the waveform epoch. For waveforms with exactly two states, such as the single transition waveform, the terms low state and high state may be used in lieu of the terms states 1 and 2, respectively.” Low state is similarly defined. The high and low states of a waveform are necessary for the computation of waveform amplitude and all other waveform parameters that require waveform amplitude in their computation.

The determination of high and low state is done by identifying which state is the most negative and most positive out of all the possible states. As mentioned in the previous paragraph, there are several methods for identifying the states of a waveform and the method used must be specified by the user.

*State boundaries*—“The upper and lower limits of the states of a waveform. All values of a waveform that are within the boundaries of a given state are said to be in that state. The state boundaries are defined by the user.” The boundaries of a state are necessary because these define the limits on the waveform values outside of which, if the waveform values exist, constitute aberration or similar waveform error. The state boundaries define the limits

of the aberration regions (described later), which are used in the computation of overshoot and undershoot (described later).

*Reference level*—“A user specified level that extends through all instants of the waveform epoch. (Mesial, proximal, and distal lines are deprecated terms because (1) line refers to consideration of and computations using a pictorial waveform representation whereas waveforms today are primarily stored in digital waveform representations and computation and viewing are done using a computer; (2) the terms mesial, proximal, and distal refer to user-defined reference levels and it is not necessary to have redundant definitions for these reference levels; (3) the terms proximal and distal cannot be used unambiguously to describe lines or points on either side of a transition of a step-like waveform because they depend on whether the step-like waveform is for a positive pulse or a negative pulse. In other words, for (3), the proximal line and points if referenced to the 10% reference level will appear to the left of a transition for a positive pulse and to the right for a negative pulse.)” These are user-specified levels that are constant throughout the waveform epoch and are specified using the same unit of measure that is assigned to a state. Reference level is usually expressed as a percent reference level, which is shown next.

*Reference level instant*—“An instant at which the waveform intersects a specified reference level.” This term describes the instant of occurrence for any user-specified level in the waveform. This is the most fundamental parameter for all other time parameters, such as pulse duration, transition duration, etc.

*Post-(or pre-) transition aberration region*—“The interval between a user-specified instant and a fixed instant, where the fixed instant is the first sampling instant succeeding the 50% reference level instant when the waveform value is within the state boundaries of the state succeeding the 50% reference level instant. The user-specified instant occurs after the fixed instant and is typically equal to the fixed instant plus three times the transition duration.” A similar definition exists for pre-transition aberration region. Overshoot and undershoot are a type of aberration that are

commonly quoted in product specifications or used to discuss the quality of a pulse. The SCOPT defined regions in the waveform in which aberrations would be defined as overshoot and undershoot. Consequently, a single-transition waveform may exhibit four of these special aberrations, pre-transition overshoot, pre-transition undershoot, post-transition overshoot, and post-transition undershoot.

#### 4. Frequently measured waveform parameters

The following parameters are the waveform parameters most commonly quoted or specified by manufacturers to describe their equipment, most commonly used to describe and compare instrument performance, and most frequently measured.

*Waveform amplitude*—“The difference between the levels of two different states of a waveform.” The Standard contains two subordinate definitions, one for signed waveform amplitude and the other for unsigned waveform amplitude. The latter is the absolute value of the former. The amplitude of a waveform is the waveform parameter from which all other level parameters are computed and from which most time parameters are computed.

Algorithm for signed waveform amplitude:

- (1) Determine  $s_1$  and  $s_2$  using a method described in Clause 5.2 of the Standard.
- (2) The waveform amplitude,  $A$ , is the difference between level( $s_2$ ) and level( $s_1$ )
  - (2.1) For positive-going transitions,  $A$  is given by:
 
$$A = \text{level}(s_2) - \text{level}(s_1).$$
  - (2.2) For negative-going transitions,  $A$  is given by:
 
$$A = \text{level}(s_1) - \text{level}(s_2).$$

This is the difference between the level occurring later in time and the level occurring earlier.

*Overshoot and undershoot*—Overshoot—“A waveform aberration within a post-or pre-transition aberration region that is greater than the

upper state boundary for the associated state level.” Undershoot—“A waveform aberration within a post- or pre-transition aberration region that is less than the lower state boundary for the associated state level. (Preshoot is a deprecated term because “pre” is a temporal prefix and “shoot,” in this context, refers to a level parameter.)” Overshoot and undershoot are ambiguous terms. Undershoot is often called preshoot, which is describing an amplitude in terms of time. Overshoot and undershoot are often interchanged when discussing the aberrations immediately preceding or succeeding a negative-going transition. The Standard eliminates this ambiguity by specifying whether the overshoot and undershoot occur before or after a transition. Accordingly, there are four possible terms, pre-transition overshoot, pre-transition undershoot, post-transition overshoot, and post-transition undershoot. Overshoot and undershoot have historically been the most often quoted waveform aberration. Computing the post-transition overshoot as the maximum error regardless of when that error occurs relative to the transition is not consistent with typical usage in which overshoot is restricted to a region near the transition. To be consistent with the present use of the terms “overshoot” and “undershoot,” the waveform around the transition is separated into pretransition and post-transition aberration regions. The duration of these regions equals three times the transition duration, unless otherwise indicated. For the pre-transition aberration region, the interval starts at the 10% reference level instant and extends toward the initial instant (first time of waveform epoch). For the post-transition aberration region, the interval starts at the 90% reference level instant and extends toward the final instant (last time of waveform epoch).

Algorithm:

- (1) Determine level( $s_1$ ) and level( $s_2$ ) using a method described in Clause 5.2 of the Standard and define the upper boundary and lower boundary for the states corresponding to these levels.
- (2) Calculate the waveform amplitude,  $A$ , as described in Clause 5.3.1.

- (3) Calculate the  $x1\%$  and  $x2\%$  reference levels and the 50% reference level as described in Clause 5.3.2. Typically used *reference levels* are the 10% and 90% *reference levels*.
- (4) Calculate the reference level instants,  $t_{x1\%}$ ,  $t_{50\%}$  and  $t_{x2\%}$ , as described in Clause 5.3.3, for the reference levels determined in step (4).
- (5) Calculate the transition duration, for the reference levels instants determined in step (5), as described in Clause 5.3.4.
- (6) Calculating the overshoot and undershoot in the pre-transition aberrations region.
- (6.1) Calculate the last instant,  $t_{pre}$ , that occurs before  $t_{50\%}$  when the waveform exits the upper (lower) *state boundary* of the low state (high state) for a positive-going (negative-going) transition using the method described in Clause 5.3.3.
- (6.2) Define the pre-transition aberration region as that between  $t_{pre} - 3t_{10-90\%}$  and  $t_{pre}$  (or as determined by the user).
- (6.3) Search the pre-transition aberration region for the maximum value,  $y_{max,pre}$ , and the minimum value,  $y_{min,pre}$ .  $y_{max,pre}$  is the maximum  $y_i$  in the pre-transition aberration region and  $y_{min,pre}$  is the minimum  $y_i$  in the pre-transition aberration region.
- (6.4) If  $y_{max,pre}$  is equal to or less than the upper state boundary of  $s_1$  ( $s_2$ ) for a positive-going (negative-going) transition then the overshoot in the pre-transition aberration region,  $O_{pre}$ , is zero, otherwise compute the percentage overshoot in the pre-transition aberration region using:

$$O_{pre}(\%) = \frac{y_{max,pre} - level(s_k)}{|A|} 100\%,$$

where  $level(s_k) = level(s_1)$  for a positive-going transition and  $level(s_k) = level(s_2)$  for a negative-going transition.

- (6.5) If  $y_{min,pre}$  is equal to or greater than the lower state boundary  $s_1$  ( $s_2$ ) for a positive-going (negative-going) transition, then the undershoot in the pre-transition aberration region,  $U_{pre}$ , is zero, otherwise compute the percentage undershoot in the pre-transition aberration region using:

$$U_{pre}(\%) = \frac{level(s_k) - y_{min,pre}}{|A|} 100\%$$

- (7) Calculating the overshoot and undershoot in the post-transition aberration region.
- (7.1) Calculate the first instant,  $t_{post}$ , that occurs after  $t_{50\%}$  when the waveform enters the lower (upper) state boundary of the high state (low state) for a positive-going (negative-going) transition using the method described in Clause 5.3.3.
- (7.2) Define the post-transition aberration region as that between  $t_{post}$  and  $t_{post} + 3t_{10-90\%}$  (or as determined by the user).
- (7.3) Search the post-transition aberration region for the maximum value,  $y_{max,post}$ , and the minimum value,  $y_{min,post}$ .  $y_{max,post}$  is the maximum  $y_i$  in the post-transition aberration region and  $y_{min,post}$  is the minimum  $y_i$  in the post-transition aberration region.
- (7.4) If  $y_{max,post}$  is equal to or less than the upper state boundary of  $s_2$  ( $s_1$ ) for a positive-going (negative-going) transition then the overshoot in the post-transition aberration region,  $O_{post}$ , is zero; otherwise compute the percentage overshoot in the post-transition aberration region using:

$$O_{post}(\%) = \frac{y_{max,post} - level(s_k)}{|A|} 100\%$$

- (7.5) If  $y_{min,post}$  is equal to or greater than the lower state boundary  $s_2$  ( $s_1$ ) for a positive-going (negative-going) transition, then the undershoot in the post-transition aberration region,  $U_{post}$ , is zero; otherwise compute the percentage undershoot in the post-transition aberration region using:

$$U_{post}(\%) = \frac{level(s_k) - y_{min,post}}{|A|} 100\%$$

*Transition duration* [Risetime, Falltime, Leading Edge, Rising Edge, Trailing Edge, Falling Edge, Time, Transition]—“The difference between the two reference level instants of the same transition (see Figs. 1 and 2). Unless otherwise specified, the two reference levels are the 10% and 90% reference levels. (The terms risetime, falltime, and

transition time, although widely used, are deprecated because they are ambiguous and confusing. First, the use of the word time in this standard refers exclusively to an instant and not an interval. Also, if the first transition of a waveform within a waveform epoch happens to be a negative transition, some users may refer to its transition duration as its risetime, and some others may refer to its transition duration as its falltime. If the use of these deprecated terms is required, then risetime is synonymous with the transition duration of a positive-going transition, and falltime is synonymous with the transition duration of a negative-going transition. If the upper and lower state boundaries of the two states are not the user-defined reference levels (for example, the 10% and 90% reference levels), then the duration of a transition is not equal to the transition duration.)” This is the most commonly quoted, referenced, and measured waveform parameter. The bandwidth of an instrument is often approximated by the equation:  $BW \approx 0.35/t_d$ , where  $BW$  is bandwidth and  $t_d$  is transition duration.

Algorithm:

- (1) Calculate the reference level instant,  $t_{x1\%}$ , for the  $x1\%$  reference level in accordance with Clause 5.3.3 that is nearest to the 50% reference level instant, unless otherwise specified.
- (2) Calculate the reference level instant,  $t_{x2\%}$ , for the  $x2\%$  reference level in accordance with Clause 5.3.3 that is nearest to the 50% reference level instant, unless otherwise specified.
- (3) Calculate the transition duration,  $t_{x1-x2\%}$ :

$$t_{x1-x2\%} = |t_{x1\%} - t_{x2\%}|.$$

## 5. Summary

The Std-181-2003 describes pulse terms, their definitions, and their methods of computation. This standard replaces the withdrawn standards, IEEE-Std-181-1977 and Std-194-1977. The major improvement in the new standard has been in the clarification and updating of the definitions section and the addition of algorithms for extracting waveform parameters. Interested and knowledgeable parties are encouraged to participate in the next revision process (please contact IEEE TC-10 chairman, currently Thomas Linnenbrink, at [linnenbrink@qdot.com](mailto:linnenbrink@qdot.com) or the SCOPT chairman, currently Nick Paulter, at [nicholas.paulter@nist.gov](mailto:nicholas.paulter@nist.gov)).

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